FINAL REPORT

"GaN Based Structures for NEA by MBE and Investigation of Nitrogen Species and Precursors for Optimum Layer Properties"

Grant No. : N00014-89-J-1780

Covering the period of

May 21, 1989 - December 31, 1997

Prepared for

the
Office of Naval Research

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Progress Made:

During the life of this grant, we have made substantial progress in the production, and processing of GaN based structures and in UV detectors and MODFETS based on GaN heterostructures. Below we give a succinct description of the progress made and list the publications that resulted from the support by ONR.

We have obtained:

ohmic contacts with resistivities below 10^{-7} Ohmcm^2 to n type GaN which are stable at 500°C,

Pt Schottky barriers with nearly a unity ideality factor which appear stable at operation temperatures of about 500 °C,

AlGaN/GaN MODFETs on sapphire substrates with 1.5 micron gate length exhibiting extrinsic transconductances of about 220 mS/mm, drain currents of about 600 mA/mm and breakdown voltages of over 100 V for a 1 μm gate-drain separation,

Inverted MODFETs on sapphire with extrinsic transconductances of about 80 ms/mm with lesser output negative conductance due to carrier confinement reducing the current path in the buffer layer,

AlGaN/GaN MODFETs on SiC with 1.5 micron gate length exhibiting extrinsic transconductances of about 180 mS/mm, drain currents of about 325 mA/mm with the negative output conductance prevalent on sapphire being absent,

GaN layers on (0001) ZnO have been grown which are smooth away from the interface, with optical properties of films comparable to the best on sapphire and better than the best on SiC and the c axis aligned with that of the substrate as determined by X ray and polarized reflectance.

We have fabricated GaN based Pin like detectors, with no anti-reflection coating, exhibiting responsivities of about 0.12 A/W corresponding to an internal quantum efficiency of about 60%, and near zero bias speed of response of about 9 ns. Though additional investigations are warranted, the speed appears to be limited by the RC time constant. At wavelengths >390 nm the responsivity drops by more than three orders of magnitude. Noise equivalent power at zero bias is limited by the instrumental noise level at 4 pW. Preliminary results with improved measurement set-up indicate the NEP to be in the tens of femtowatt.

The UV detectors are imperative in military systems because of the continuing proliferation and increasing lethality of anti-aircraft missiles pose a grave threat to military

aircraft. At altitudes below ~30,000 ft, the ultraviolet (UV) spectral region from 260-290 nm is nearly ideal for detecting missile plumes against a dark background.

The current UV missile warning sensors uses photomultiplier-based sensor arrays which are bulky, have limited sensitivity due to extensive optical filtering and photon-to-electron conversions and suffer from increased background noise due to detection of long wavelengths outside the solar-blind region. By comparison, solid state photodetectors offer the advantages of being compact, rugged, and potentially cheap. In addition, solid state detectors have near-unity quantum efficiency and offer superior rejection of long wavelength background light. This important application underscores the impact of our accomplishments in the UV detector area.

Most Recent Accomplishments in GaN on ZnO Substrates:

- Hamdani, A. Botchkarev, W. Kim, A. Salvador, Ö. Aktas, H. Morkoç, M. Yeadon, J. M. Gibson, S.-C. Y. Tsen, D. J. Smith, D. C. Reynolds, D. C. Look, K. Evans, C. W Litton, W. C. Mitchel, and P. Hemenger, "Optical properties of GaN grown on ZnO by Reactive MBE" Appl. Phys. Letts. Vol. 70, No. 4, pp. 467-469, (1997).

High quality wurtzite GaN epilayers have been grown on ZnO(0001) substrates by reactive molecular beam epitaxy. Photoluminescence and reflectivity measurements point to high quality presumably due to the near match of both the crystal lattice parameter and the stacking order between GaN and ZnO. In addition, the good films lack the characteristic yellow photoluminescence band. Any misorientation of the GaN epilayer planes with respect to the ZnO substrate is not detectable with polarized reflectivity. The x-ray double crystal diffraction measurements indicate this misorientation is much smaller than those for GaN epilayers on SiC and Al_2O_3.

- Hamdani , M. Yeadon, David. J. Smith, H. Tang, W. Kim, A. Salvador, A. E. Botchkarev, J. M. Gibson and H. Morkoç, " Microstructure and optical properties of epitaxial GaN on ZnO(0001) grown by reactive molecular beam epitaxy", J. Appl. Phys. in press.

High quality GaN epilayers has been grown on O and Zn surfaces of ZnO(0001) substrates by reactive molecular beam epitaxy. We present an investigation of the effect of the intermediate buffer layer on the structural and optical properties of the GaN films. The optical and structural characterization of both GaN epilayers and ZnO substrate have been performed using photoluminescence, reflectivity, x-ray double diffraction, atomic force microscopy and transmission electron microscopy. The optical results indicate that GaN is grown with compressive strain due to the difference in thermal expansion coefficient between GaN and ZnO. The surface roughness has been reduced by using an intermediate low temperature buffer layer of GaN. The photoluminescence spectra at low temperature of GaN/ZnO epilayers do not reveal any appearance of the well known midgap yellow signal. Linear polarized reflectivity and photoluminescence results indicate that GaN epilayers planes are not misoriented with respect to the ZnO substrate planes, this fact is confirmed by x-ray double diffraction measurements.

Hamdani, A. Botchkarev, H. Tang, W. Kim, and H. Morkoç "Effect of Substrate Surface Polarity and Buffer Layer on the Growth of GaN on ZnO by Molecular Beam Epitaxy" Appl. Phys. Lett., in press.

The effect of substrate surface polarity, O and Zn faces, on the quality of GaN epitaxial layers grown on ZnO(0001) substrates by reactive ammonia molecular beam epitaxy has been investigated. The possible effects dealing with the disparity in surface preparation of the two faces have been eliminated. Photoluminescence and reflectivity measurements demonstrate that the oxygen-face leads to higher quality GaN on ZnO compared to the zinc-face. We also present optical data obtained by using low temperature AlN, GaN and $In_xGa_{1-x}N$ buffer layers. The best result has been obtained with nearly lattice matched $In_{0.20}Ga_{0.80}N$ buffer layer.

Carrier dynamics in GaN/AlGaN quantum wells are pivotal in electronic and optoelectronic devices in this important material systems. While short carrier lifetimes in absence of non-radiative recombination lead to efficient light emission, in general it is sign of non-radiative recombination and extreme localization. By producing micro-disks, we were able to extend

the excitonic lifetimes in GaN/AlGaN quantum wells as outline below.

- A. Mair, K. C. Zeng, J. Y. Lin, H. Jiang, B. Zhang, L. Dai, H. Tang, A. Botchkarev, W. Kim, and H. Morkoç, "Optical Properties of GaN/AlGaN Multiple Quantum Well Microdisks" Appl. Phys. Lett., in press.

An array of micro-disks with diameter of about 9 μm and spacing of 50 μm has been fabricated by dry etching from a 50 _/50 _ GaN/$Al_xGa_{1-x}N$ (x_0.07) multiple quantum well (MQW) structure grown by reactive molecular beam epitaxy. Optical properties of these micro-disks have been studied by picosecond time-resolved photoluminescence (PL) spectroscopy. PL emission spectra and decay dynamics were measured at various temperatures and pump intensities. With respect to the original MQWs, we observe strong enhancement of the transition intensity and lifetime for both the intrinsic and barrier transitions. The intrinsic transition is excitonic at low temperatures and exhibits an approximate 10 fold increase in both lifetime and PL intensity upon formation of the micro-disks. This implies a significant enhancement of quantum efficiency in micro-disks and a bright future for III-Nitride micro-cavity lasers.

- ZnO epitaxial layers have been grown by MBE. These preliminary and successful attempts utilized sapphire substrate for cost reasons. Even then, films showed strong interference fringed below the gap at room temperature. Both water vapor and reactive oxygen supplied by an electron cyclotron resonance(ECR) source have been utilized for the group VI element. A substrate temperature range of 500 to 700 °C has been explored with higher substrate temperatures resulting in lower background carrier concentrations and stronger interference fringes. Plans are under way to repeat these experiments on ZnO substrates and explore even higher growth temperatures. Nominally, a growth rate of about 0.5 μm/hour has been employed. The films show sharp and strong bandedge absorption and excitonic emission. Mg has also been incorporated with resultant increase in the bandgap.

Publications resulting under this program:

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